INCUBATION EFFECTS IN PROBLEM SOLVING

Technical Report AIP - 57

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ABSTRACT

Does putting a problem aside "to incubate" for a while really facilitate problem solving, and if so, why? We answer this question by reviewing the empirical literature, by reviewing existing theories of incubation, and by proposing a new more unified approach.

We begin by defining incubation. Next, 17 studies of incubation are reviewed and their results compared. Factors that affect whether an incubation effect is obtained are discussed. These factors pertain to the type of problem studied, the length of the time period for problem solving before the incubation period, the length of the incubation period, and the type of activity during the incubation period. We also examine the role of individual differences in obtaining incubation effects. Finally, we propose a theory of incubation, whereby incubation effects depend upon an interaction between the cause of blockage in problem solving and cognitive mechanisms that act during the incubation period. Potential causes of blockage in problem solving are (a) the inability to generate new paths to solution and (b) stereotypy. Critical cognitive mechanisms include (a) priming and (b) forgetting. Priming during a period of incubation helps on problems where the difficulty lies in generating new solution paths, whereas forgetting during an incubation period helps on problems where stereotypy is blocking problem solution. Implications for further problem solving research on incubation, insight, and transfer are discussed.

Keywords: Thinking, artificial intelligence; [illegible]

Does putting a problem aside to "incubate" really help? Most people we have asked believe in the phenomenon of incubation, based on their own experience. Certainly the literature on incubation is full of anecdotal accounts that seem to corroborate these intuitions (e.g., see Ghiselin 1952; Hadamard 1954; Koestler 1964; Platt & Baker, 1931). However, experimenters attempting to d nonstrate incubation effects in the laboratory have reported mixed results. Some researchers (e.g. Olton, 1979; Olton & Johnson, 1976) have even been led to question whether the phenomena of incubation exists at all. As Merton (1987) has pointed out, establishing the existence of a phenomenon is a basic, though sometimes overlooked, prerequisite to explaining it.

The first aim of this paper is to establish the phenomenon of incubation by critically examining the empirical base upon which the claim for the existence of incubation rests. Appealing as they are, anecdotes are poorly suited to replication and have therefore been omitted from the first part of our discussion.

Our second aim is to summarize the factors that have been manipulated in incubation experiments. A detailed examination of the results of such manipulations not only helps one understand apparent anomalies in the literature, but also provides the foundation for building a unified theory of incubation effects.

Our last aim is briefly to review proposed theories of incubation in light of the experimental evidence. It is here that anecdotal accounts of incubation become relevant as aids to clarifying different theoretical positions. Ultimately we will argue for (and present an example of) a unified theory of incubation as the best way to explain the diverse experimental findings.

Definitions

Part of the confusion surrounding incubation stems from the fact that different researchers use the term to mean different things.

Woodworth (1938) tells us that Wallas (1926) was the first to use the word "incubation" in a psychological sense, although Hemholtz (1896) and Poincaré (1908) had referred to the same phenomenon earlier. Wallas considered incubation as a stage in the creative process that followed preparatory work on a problem, but preceded the moment of illumination or insight. Use of the word "incubation" to refer to a stage of thought has since been adopted by various psychologists over the years (e.g., Glass & Holyoak, 1986; Hadamard, 1945; Patrick, 1935). For all of these researchers, the hallmark of the incubation stage is the act of putting the problem aside and attending to other matters. The incubation period is over when a sudden illumination occurs or when the problem solver resumes conscious problem solving and then achieves insight.

Although this definition of incubation is intuitive and fits anecdotal evidence quite well, it does not suffice for experimental study of the phenomenon. The stage-of-processing definition of incubation is theoretical. In particular, it is tinged with the assumption that unconscious work is being done during the incubation period. Besides the fact that arguably better theories of incubation exist, a phenomenon cannot be established by beginning with an explanation. Rather, an operational definition is the place to begin. Theory can follow once we are sure there is something to explain.

Patrick (1935) proposed one of the earliest operational definitions of incubation. She defined incubation as the "recurrence of ideas" during a problem-solving episode. For example, if one of her poet subjects initially considered an idea for a poem, then dropped that idea temporarily to consider other ideas, and later returned to the initial idea, Patrick counted this behavior as evidence of incubation. However, viewed through the lenses of information processing psychology, Patrick's "incubation" seems more like evidence for use of the Best-First Search problem-solving heuristic (Rich 1983, p. 78).[1] The momentary abandonment of, and return to, an idea within a single problem-solving episode is at the very least on a different time scale from the incubation referred to by Hemholtz, Wallas, and Poincare. Moreover, Patrick left open the question of whether incubation was actually beneficial (although the established effectiveness of Best-First Search suggests that incubation as defined by Patrick should be a boon).

More recently, experimenters have focused on whether an interruption of problem solving is beneficial. The most popular paradigm has been to compare the effectiveness of time spent working on a problem continuously with the same amount of time distributed over two or more work sessions separated by breaks.[2] In accord with this paradigm, we define incubation as **any positive effect of an interruption on problem-solving performance.** This definition is atheoretical -- as it must be if we are to establish the

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[1]Briefly, Best-First search involves evaluating each idea that has been generated so far and choosing the most promising one for further exploration. After a certain amount of exploration, the evaluation process is repeated. A certain idea may look promising initially, but will be dropped if further exploration makes it less attractive than another idea. However this second idea may also become less attractive upon further exploration leading to a return to the initial idea. Thus, Patrick's "recurrence of ideas" is a natural consequence of the use of Best-First Search.

[2]A variant of this paradigm is to compare the effectiveness of time spent working on a problem continuously with the same time spent over two or more work sessions **including** the time spent on breaks.

existence of a phenomenon. Moreover, it is also the one adopted by the vast majority of experimental studies on incubation.

Experimental Studies of Incubation

Of the 17 studies we have identified as directly testing incubation effects, 11 found an incubation effect (i.e., a beneficial effect of an interruption on problem solving relative to a continuous-work control condition) in at least some conditions. Another four reported incubation effects but defined incubation differently, namely, as recurrence of ideas that were abandoned earlier in a problem-solving episode (Eindhoven & Vinacke, 1952; Patrick, 1935, 1937, 1938). Of the remaining two, one study found the continuous-work control group to perform better than all but one of the interrupted groups (Gall & Mendelsohn, 1967). The other failed to find incubation effects of any kind (Olton & Johnson, 1976).[3]

While these numbers generally support the existence of incubation as we have defined it, the story is complicated by reports of failures to replicate results across laboratories (Olton, 1979; Olton & Johnson, 1976; Silveira, 1971), results that seem in apparent conflict (Dominowski & Jenrick 1972; Murray & Denny, 1969), and questionable interpretations of results (Kirkwood, 1984). We believe the best way to understand these complications and work toward their resolution is to examine the factors that might affect incubation.

Manipulation of Factors

Factors that potentially affect incubation include the type of primary task used, the timing and length of the interruption period, the nature of the activity performed during the interruption period, and individual differences in subjects' abilities and knowledge. Table 1 lists the 17 studies reviewed in this article, the primary tasks used in each experiment, the length of the experiment, and whether the interpolated activity is related or unrelated to the primary task in at least some conditions. Because we are using a very specific definition of incubation, **any positive effect of an interruption on problem solving**, allowances were made for studies that define incubation differently, or whose designs do not allow comparisons between interrupted and continuous work. These studies are included for completeness in Table 1, but have been marked N.P. (Non-Paradigmatic) in the last column of the table.

<INSERT TABLE 1 ABOUT HERE>

[3]Olton (1979) cites two additional studies that failed to find an incubation effect: Olton (unpublished) and Dominowski (1972). However, neither of these papers has been published (to our knowledge), and hence they were unavailable for review.

In most studies of incubation, there is at least one control group that works continuously on the problem. The experimental groups may be subjected to interruptions of varying lengths and the timing of the interruption is often varied as well. Sometimes subjects know that they will be returning to the initial problem after the interruption, sometimes not.

The simplest incubation paradigm is to interrupt work on the primary task for an interval of time, and then allow subjects to return to the task. In the simplest case, no attempt is made to manipulate the nature of the interpolated activity, except, in some cases, to ensure that subjects do not consciously work on the primary task during the interruption period. That is, subjects typically perform an unrelated activity during the interruption period. In addition, no attempt is made to manipulate the ability level of the subjects. In contrast, other experiments manipulate either the type of activity performed during the interruption, or the ability level of the subjects, or both.

It is worth noting that our definition of incubation -- **any positive effect of an interruption on problem solving** -- says nothing about what occurs during the interruption. As one might expect, however, the nature of the activity performed during the interruption can be of critical importance. Similarly, the length of the **preparation** period -- the time subjects are allowed to work on the problem before the interruption-- can make a big difference for some problems, as can the length of the interruption itself. One would also expect that these factors might interact with the type of task subjects are asked to solve (primary task) and with individual differences in subjects' knowledge and abilities.

Primary Tasks

The first thing to notice about the primary tasks used in experimental studies of incubation is that, without exception, they involve non-routine problem solving. The domains include composing poems, drawing pictures, designing experiments, finding solutions to problems of campus life, thinking of remote consequences for a given hypothesis, solving puzzle problems that require physical manipulation or construction, as well as puzzles that are more abstract, solving anagrams, and producing remote or unusual responses to verbal stimuli. Nowhere do we find experimenters using tasks, such as long division, which presumably require only that subjects execute a known algorithm. Instead, all investigators seem to share the belief that incubation effects will be observed only when there is the opportunity to create something new, or when something unknown must be discovered.

A second observation is that the tasks range widely from complex, ill-defined problems (e.g., discussing ways to develop greater rapport between students and faculty [Kirkwood, 1984]) to puzzles whose answers and possible approaches are quite well-defined (e.g., anagrams [Peterson. 1974]) The tasks also vary in the amount of time allowed to complete them, ranging from 60 seconds in the case of items on the Remote Associates Test (Mednick. Mednick. & Mednick. 1964) to two or three weeks in the case of designing a scientific experiment (Patrick, 1938). However, the vast majority of tasks that have been studied for incubation effects take less than an hour to complete.

This last point often leads to the objection that laboratory studies may lack ecological validity. and that this lack poses a major difficulty for any attempted study of incubation. Although realistic studies are to be encouraged, there are at least two reasons for believing that progress can be made in the laboratory First, the majority of published studies on incubation have found that an incubation period facilitates problem-solving performance. Second, a useful explanation of incubation will most probably rest upon mechanisms that operate well within the time frame allowed by typical laboratory experiments. These mechanisms will become evident as we examine individual experiments more closely.

In short, the current literature on incubation is based primarily on creative tasks that can be solved within the time constraints of a *short laboratory experiment.*

Subjects' Knowledge of Returning to the Task

Do incubation effects occur only when subjects know that they will be returning to the primary task after the break in problem solving?

Fulgosi and Guilford (1968) hypothesized that subjects who expected a second chance to work on a problem would be more likely to show an incubation effect than subjects who did not. They asked subjects to generate as many consequences as possible given the questions: "What would be the results if everyone suddenly lost the ability to read and write?" and "What would be the results if none of us needed food anymore to live?". Both the number and quality ("remote" or "obvious") of consequences were judged independently (inter-rater reliability = .84) by three raters who were blind to the experimental conditions.

Subjects either worked on the task continuously for four minutes, or worked for two minutes, were interrupted for either ten or twenty minutes, and then resumed work for another two minutes. The interruption task consisted of 25 number-series problems of difficulty such that no subject completed all of the problems within the 20-minute interval. Half of the subjects in each incubation group knew that they would be returning to the consequences task after the interruption; half did not know.

Fulgosi and Guilford found that subjects in the 20-minute incubation condition generated significantly more consequences than subjects in either the continuous-work condition or the 10-minute incubation condition. Furthermore, subjects' knowledge of whether they would be returning to the consequences task after an interruption did not seem to affect the results.

Consistent with this second finding are the results of an experiment by Dreidstadt (1969). Dreistadt gave subjects two types of puzzle problems to solve. His control subjects worked on a puzzle continuously for 20 minutes. The experimental group worked in accordance with the following instructions:

It has been found that when trying to solve a problem, it often helps the person to solve the problem if he 'puts the problem aside' for awhile and then continues on it later. You have five minutes in which to solve the problem, then a break of eight minutes, and then seven more minutes to solve the problem. (Dreistadt, 1969, p.164)[4]

Dreistadt found incubation effects on one problem but not on the other, suggesting that the knowledge about returning to the problem, knowledge of when the break would occur, knowledge of the length of the break, and even potential demand characteristics of being placed in an experiment where one knows the expected outcome, were not the crucial factors in bringing about incubation.

Of the remaining studies reporting incubation effects, three explicitly mentioned forewarning subjects that they would be returning to the interrupted tasks (Kirkwood, 1984; Murray & Denny, 1969; Patrick, 1938; Silveira, 1971). One (Dominowski & Jenrick, 1972) explicitly states that subjects were **not** informed that they would return to the interrupted task. Five were not specific on this point (Fulgosi & Guilford, 1972; Mednick et al., 1964; A. Patrick, 1986; Peterson, 1974). And two (Patrick, 1935, 1937) did not compare continuous work to interrupted work, so the question of subjects' knowledge of returning to the task did not apply.

Of the two studies reporting negative or null effects of an incubation period, one does not mention forewarning subjects that they would be interrupted (Gall & Mendelsohn, 1967). In the other study (Olton & Johnson, 1976), subjects were explicitly informed that they would return to work on the unfinished problem.

[4]Note that this design counts the interruption period as part of the total time allowed for work on the puzzle. In contrast most other studies of incubation consider the sum of the time spent before and after the break to be the right length of time to compare with the comparative continuous work control group. Dreistadt's design is a stricter test of incubation because it assumes that the time spent during the interruption period is at the expense of time spent in continuous work on the problem.

In sum, knowledge about returning to the interrupted task does not seem to play a role in producing (or inhibiting) incubation. Studies report incubation effects both when subjects were forewarned, and when they were not. Similarly, studies have failed to find incubation effects under both knowledge and no-knowledge conditions. Perhaps the most telling evidence is that a study specifically designed to test the effects of differential knowledge found no differences in incubation effects (Fulgosi & Guilford, 1968). Variations in the information provided to subjects about the length and/or timing of the interruption, or even that the interruption was expected to have a positive effect, have not seemed significantly to have affected incubation.

Length and Timing of Interruption

When should a subject be interrupted on a task if incubation is to have maximum benefit and how long should that interruption be? To our knowledge, only three studies have addressed these questions directly, although an examination of the literature as a whole will provide additional information on these issues.

Silveira, who wrote her thesis on *The effect of interruption timing and length on problem solution and quality of problem processing,* devoted some attention to these questions. She used the cheap-necklace problem as her task. The problem is as follows: "A man has 4 chains, each 3 links long. He wants to join the 4 chains into a single closed chain. Having a link opened costs 2 cents and having a link closed costs 3 cents. The man had his chain joined into a closed chain for 15 cents. How did he do it?" (Silveira, 1971, p. 178). Her first experiment involved a control condition and four experimental conditions corresponding to a 2 X 2 factorial design: early and late interruption of problem solving X short and long interruption length. Silveira started timing subjects from the point where they understood the problem sufficiently so that they were able to make an attempt to solve it. Early-interruption subjects were interrupted 3 minutes after this point and were allowed to work for an additional 32 minutes upon their return to the problem. Late-interruption subjects were interrupted after 13 minutes, and were allowed 22 minutes upon their return to the problem. Control subjects worked continuously for 35 minutes on the problem.

The length of the incubation period for any given subject was independent of *when* he or she was interrupted. Both early- and late-interruption subjects took breaks of either 30 minutes (the Short-Interruption subjects) or 3.5 hours (Long-Interruption subjects). Of the four experimental groups (Early-Short, Early-Long, Late-Short, Late-Long), only the Late-Long subjects showed evidence of incubation when compared with the control group. This better performance of the Late-Long group compared with continuous work was replicated by Silveira in a second experiment with tighter methodological controls. Her results support the interpretation that a sufficient preparation period (13 minutes in this case) is needed before an interruption is likely to have a beneficial effect.

A second implication of Silveira's finding that her Late-Interruption/Long-Interruption groups demonstrated incubation is that longer interruptions may be better than shorter ones. This issue of the length of interruption was explicitly examined in the studies by Fulgosi and Guilford.

First, note that Fulgosi and Guilford (1968, 1972) found that only two minutes appeared to be adequate preparation time for the Consequences Test item (e.g. "What would be the results if none of us needed food anymore in order to live?"). Presumably, the difference between their results and Silveira's can be explained by the discrepancy in the tasks used. Whereas Silveira used a relatively complex problem-solving task, Fulgosi and Guilford used tasks that required only retrieving or generating ideas from memory. If we assume that the purpose of preparation is to gain familiarity with (or "chunk") the problem elements and possible manipulations (as argued by Simon, 1966), then it follows that tasks with more novel elements should require more preparation time.

With regard to the length of interruption, Fulgosi and Guilford (1968) found a 20-minute interruption interval to be significantly more beneficial than either continuous work on the problem or a 10-minute interruption. Although there was a trend for the ten-minute interval to be of some benefit, it did not differ significantly from continuous work. As a test of the range of beneficial interruption lengths, Fulgosi and Guilford (1972) conducted a similar study in which they found that a 30-minute interruption was significantly more beneficial than either continuous work or a 60-minute interruption. This finding suggests that there may be an optimum length of interruption for a given task. For the short tasks used in Fulgosi and Guilford's experiments, the optimum length seem to be about 25 minutes, whereas in Silveira's more complex task, a 3.5-hour interruption was preferable to a .5-hour interruption.

Although the remaining experimental studies do not test the effects of length of interruption directly, we were curious to see whether an examination of the incubation literature as a whole might give us some clue as to the optimal interruption length to produce incubation effects. Although the tasks vary widely in complexity, researchers hoping to find incubation usually take the complexity of the task into account when deciding how much time to allow before the interruption. In effect, there is implicit (and often explicit) agreement that incubation can only happen to the prepared mind -- a fact that Silveira has demonstrated experimentally.

Specifically, we were interested in whether there might be some consistent relationship between the amount of preparation time allowed (roughly taken as an index of the problem's complexity) and the length of the interruption period.

Table 2 lists all 17 studies along with the relevant information. Studies in the first quarter of the table reported incubation effects attributable to time spent away from the problem either doing nothing or performing unrelated tasks. Studies listed in the second quarter of the table reported an incubation result only in conditions where factors other than time away from the problem were involved. These factors included receiving hints or priming, performing a related task during the interruption, and incubation effects that were observed only with subjects selected for high or low ability. Studies in the third quarter of the table reported negative or null effects of interruption in one or more conditions compared to a continuous-work control. Finally, the experimental design of studies listed at the bottom of the table did not allow a quantitative comparison of the preparation time and the interruption time.

<INSERT TABLE 2 ABOUT HERE>

Column 1 of Table 2 indicates which interruption period produced the greatest improvement in subjects performance. Column 2 lists how much preparation time was given before the interruption. Column 3 shows the ratio of critical interest -- the length of the interruption period to the amount of time allowed for preparation.

The most striking result from Table 2 is that interruption alone appears to be beneficial when the ratio of interruption time to preparation time ranges from 6:1 to 16:1. When this ratio drops below 3:1 incubation can be obtained only when other facilitating factors are introduced (e.g., priming during the interruption period). Thus, the data in Table 2 suggest that there may be a lower bound on the length of the interruption period relative to preparation time if incubation is to occur. Since only one study has been done where this ratio is extremely large (Mednick et al., 1964), it would be premature to infer the existence of an upper bound on this ratio, although potential existence of both bounds should be explored in future experiments.

In sum, our analysis of the effects of length and timing of interruptions confirms the popular wisdom: Preparation is necessary for incubation to occur and the interruption must occur after an adequate preparation interval. However, the analysis goes further in that it suggests a relationship between the length of the incubation interval and the complexity of the task and preparation period. Although it is theoretically possible to specify an operational measure of complexity, for our purposes, we have made the simplifying assumption that experimenters implicitly took the complexity of their task into account in determining the length of the preparation period. In addition, some experimenters gave subjects more total time to work on the problems than did other experimenters. We found that the amount of total time given, which is a standard measure of task difficulty, was correlated highly (.94) with the amount of preparation time that was allowed. In general, longer preparation times were associated with longer total times. Having made these assumptions, it was possible for us to compare the length of the interruption with the length of the preparation period. This ratio varied over a narrow range of values for studies reporting incubation effects without the facilitating effects of other factors. Studies reporting null or negative effects typically had a much lower interruption:preparation ratio, suggesting that there may be a critical minimum length of the incubation period for a given task.

Nature of the Interruption

Critical to our distinction between simple and complex incubation effects is the nature of the activity that subjects perform during the period of interruption. Specifically, because many writers on the subject of incubation have suggested that interruption provides an opportunity for some new experience to happen that later helps problem solving, it is important to distinguish between interruption activities that are related and those that are unrelated to the problem.

Related activities include priming the subject, providing (subtle) hints, or having the subject engage in a task that might be expected to provide positive transfer to the initial problem. Good examples of these types of studies are those done by Dreistadt (1969), Gall and Mendelsohn (1967), Kirkwood (1984), and Olton and Johnson (1976).

Kirkwood studied the effects of interruption on group problem-solving behavior. An instantiation of his experimental design follows: A continuous-work control group discussed the problem of how to improve student-faculty rapport for 30 minutes. A related-interruption group discussed improving student-faculty rapport for 10 minutes, then discussed ways of creating a more friendly atmosphere among students for 10 minutes, and finally returned to the initial topic for 10 additional minutes. An unrelated-interruption group was identical to the related-interruption group except that the second topic of discussion was on ways to reduce the amount of energy students use.

Kirkwood found (after scores were adjusted for problem difficulty) that subjects in the unrelated interruption condition produced significantly more solutions ($p<.05$, one-tailed) in their final ten minutes than did control subjects in the final ten minutes of their work. Kirkwood also reported a non-significant trend for the related interruption to produce more solutions than did continuous work. Based on these results, Kirkwood suggested that an incubation period may be beneficial only if the activity during the break differs from the initial task.

However, a major qualification of Kirkwood's results is in order. Most troublesome is the fact that both of Kirkwood's interruption groups were generating more solutions to the initial task even *before* the incubation period! Controlling for this initial advantage of the incubation groups, the incubation effect completely disappears.[5] Kirkwood suggests that the better performance of the interrupted groups may be due to the fact that they felt more pressured to generate solutions rapidly in the first 10 minutes because they knew they would be moving on to another task. However, we agree most strongly with Kirkwood's conclusions that "further research is needed to replicate the results of this study."

In contrast to Kirkwood's suggestion that activity during the interrupted period ought to be quite different from that of the primary task, Dreistadt's (1969) study suggests that similarity might be more helpful. Dreistadt had subjects work on one of two insight problems: the farm problem or the tree-planting problem.

For the farm problem, subjects were presented with a picture of a "farm" of dimensions nxn that had a square piece of dimensions .5n x .5n removed from one of the corners. The instructions were: "Divide the area of the farm into four parts which have the same size and shape." The tree-planting problem consisted of 10 arrows symbolizing trees along with the instructions: "Plant 10 trees in 5 rows with 4 trees in each row."

Subjects either worked on one of these problems continuously for 20 minutes (continuous-work groups) or worked for 5 minutes, guessed playing cards for 8 minutes, and then returned to the problem for an

[5] The method used was as follows: Determine the difference between the control group and an incubation group before the interruption by simple subtraction. Add this difference to the score of the incubation group after the interruption. Compare the adjusted scores.

additional 7 minutes of work (interruption groups). Subjects in both groups were further divided into those who saw "pictorial analogies" and those who did not. The pictorial analogies consisted of three pictures for each problem that showed the shapes needed to solve the problem. Half of the interrupted subjects and half of the continuous-work subjects worked on their problem while these pictures stood in front of them on a Bristol board. The remaining subjects did not have the benefit of these pictures.

Dreistadt found that the pictorial analogies helped subjects solve the problems, regardless of whether subjects were interrupted. Moreover, in the case of the farm problem, there was a significant interaction between pictorial analogies and interruption. That is, even though interruption alone was no better than continuous work, interruption combined with visual analogies was of more help than seeing the visual analogies in the continuous-work condition. On the basis of these results, Dreistadt suggested that incubation involves more than simple recovery from fatigue or the breaking of a mental set. An incubation period also provides an opportunity for subjects to find a new direction to pursue upon their return to the problem. Subjects exposed to the visual analogies were able to use the visual information in their environment (although not necessarily consciously) to generate a new approach to the problem. However, subjects in the more restricted visual environment had fewer opportunities to find a new problem-solving direction during the interruption.

It is noteworthy that Dreistadt found a benefit of interruption even though the interruption was at the expense of conscious work on the problem.[6] In effect, Dreistadt's results indicate that time spent during the interruption (in the pictorial-analogy condition) is more productive than the same amount of time spent consciously working on the problem. The implication is that incubation, at some level, involves processes different from those that are taking place during continuous problem solving. Specifically, Dreistadt suggests that breaking of set occurs, and that this process is useful when it occurs in an environment rich in material that is relevant to the problem.

Although quite striking, Dreistadt's results must be viewed in the context of Olton and Johnson's (1976) failure to replicate these results. Olton and Johnson's study is quite interesting in its own right, because in addition to attempting to replicate Dreistadt's finding that visual analogies plus interruption benefited performance on the farm problem, Olton and Johnson explored the effects of an entire range of

[6]As noted earlier, whereas most incubation studies compare the amount of work done before and after the interruption with an equivalent amount of continuous work, Dreistadt proposed a tougher comparison. He compared the total time spent by the incubation subjects (*including* the interruption period) with an equivalent amount of time spent in continuous work on the problem.

interruption activities. Some subjects worked on the farm problem continuously, but others were given demanding cognitive tasks during the interruption (e.g., the Stroop task and counting backwards by threes), or they listened to a lecture on set breaking, or they relaxed in a comfortable chair with soft music playing, or they were asked to review what they considered to be the important elements of the problem, or they simply did nothing but wait. Somewhat surprisingly, no incubation effects were found for any of the interrupted groups relative to the controls. In particular, these results differed from Dreistadt's in that Olton and Johnson found no benefit for interrupted groups that also had visual analogies made available.

Olton and Johnson's study differed from Dreistadt's in a number of ways. For example, Olton and Johnson's interrupted subjects worked for 10 minutes followed by a 15-minute interruption and 20 more minutes of work on the farm problem. Their control subjects worked continuously for 30 minutes. In contrast, Dreistadt's subjects worked for only 20 minutes (including the interruption -- if they were in an interruption group). By examining segments of their data that correspond in length to Dreistadt's conditions, Olton and Johnson were able to estimate the results of a more exact replication of Dreistadt's experiment. The conclusion is the same: The interrupted group did no better than the control group. In fact, there is a trend suggesting it actually did worse. One factor that cannot be accounted for is the difference in the length of the interruption periods in the two experiments (Dreistadt's 8 minutes versus Olton and Johnson's 15 minutes). However, it is difficult to see how this discrepancy would produce such different results.

The most likely explanation of the differences lies in the extremely good performance of Olton and Johnson's continuous-work control groups relative to that reported by Dreistadt. Olton and Johnson argued:

In Dreistadt's study, 70% of the subjects in the group with the prominent visual analogies solved the problem (in 13 min. of work time) and only 10% of the subjects in the control group did so (in 20 min. of work). The corresponding figures from the present study were 38% and 56% respectively, and when the standard [i.e., Olton and Johnson's] controls with 30 min total working time are used as a reference, the corresponding figures were 50% and 53%. Thus, regardless of which set of times is used, the performance of the controls in the present study was strikingly superior to the behavior of Dreistadt's controls. Indeed, given such high performance by a control group, even a treatment group that did achieve a solution rate of 70% might not differ significantly from it.

We are inclined to agree with Olton and Johnson's analysis of the discrepancy in results. However, without further research on the farm problem, it would be difficult to determine which control group was exhibiting the anomalous behavior.

As a final example of how the nature of the interruption activity can affect incubation, consider the study by Mednick, Mednick, and Mednick (1964). Mednick et al. investigated the relationship between creativity (as measured by the Remote Associates Test), priming, and incubation. They gave subjects a series of three-word items such as *surprise line birthday* and asked the subjects to respond with a single associated word within a one-minute time limit. For example, in this case, the answer would be *party*, because it can be combined with the stimulus items to form *surprise party, party line*, and *birthday party*.

Ten items that subjects failed to solve were presented again. Subjects were primed with the answer to half of these items during an interpolated task that involved solving analogies. The answers to some of the analogies were identical to the answers required to solve five of the difficult items that were presented a second time in the primary task. Mednick et al. found that subjects did significantly better in the primary task on the items that were primed during the interpolated activity, despite the fact that no subjects reported being aware of the connection. Inasmuch as Mednick et al. believed that one function of the incubation period is to introduce new associative elements, these results supported their hypotheses. However, the very short duration of the analogy task seems incongruous with what we might normally consider an incubation period. To address these concerns, as well as to explore the relationship between creativity as measured by the Remote Associates Test (RAT) and incubation, Mednick et al. conducted a follow-up experiment.

Their second experiment was similar to the first except that the interruption period between the end of the analogy task and the second presentation of the ten previously missed items was either 0 or 24 hours. For the 24-hour interruption conditions, half of the subjects received the prime before the interruption and half received it at the end of the interruption. Again, it was found that primed subjects gave more correct answers that non-primed subjects, regardless of the length of interruption. Most striking, however, was the result that high- and low-scorers on the Remote Associates Test differed significantly in their performance after an interruption, without regard to priming. Whereas the positive priming results suggest that specific associative priming may be a component of incubation, Mednick et al. pointed out that some incubation occurred in the absence of priming. Even more intriguing is the fact that this simple incubation effect occurred mainly for the subjects with high scores on the Remote Associates Test. This result suggests that incubation may be a phenomenon that is subject to individual differences -- a topic that we will take up shortly.

Table 3 lists the 13 studies that operationalized incubation as any benefit of interruption over continuous work. Also included are the primary tasks that were used, the variety of activities occurring during the interruption periods, and the outcome of the studies.

<INSERT TABLE 3 ABOUT HERE>

From Table 3 it should be clear that incubation effects have been obtained with a wide variety of interpolated tasks. Moreover, Table 1 and Table 3 considered together show that it is not simply whether the interpolated is related to the primary task or not that determines the presence or absence of incubation. Rather incubation appears be the result of a complex interaction of factors. Integrating these factors into a coherent framework will be a major goal of our theoretical discussion. Before moving to theory however, we consider a final factor that is often overlooked: individual differences.

Individual Differences

Questions about incubation periods have generally been posed in terms of whether they facilitate problem solving. Researchers clearly disagree, with some of them finding facilitation (Fulgosi & Guilford 1968, 1972; Peterson, 1971; Silveira, 1971) and others not finding it (Gall & Mendelsohn, 1967; Olton & Johnson, 1976). The literature on this topic is contradictory. We believe that part of the contradiction stems from individual differences in subjects' abilities to benefit from an incubation period. Unfortunately even here the literature seems contradictory, with some studies showing that interruptions help high ability subjects (Dominowski & Jenrick, 1972; Patrick, 1976) and others showing they have a slight effect (Mednick, Mednick, & Mednick 1964) or are even harmful (Murray & Denny, 1969).

Dominowski and Jenrick (1972) divided subjects into two ability groups based on performance on the Gestalt Transformation Test (GTT). The subjects were then asked to solve Maier's hatrack problem (Maier 1945). In some conditions, a hint for solving the problem was given while subjects were continually working on the problem or after they had been given an interpolated activity. Dominowski and Jenrick found that subjects with high scores on the GTT performed better on the hatrack problem when a hint was given after an interpolated activity than when the hint was given during continuous work on the problem. In contrast, subjects with low scores on the GTT performed better when a hint was given during continuous work on the problem. Dominowski and Jenrick suggest that the high-ability subjects had reached a dead end on the problem. When a hint was given in a neutral context, it could be utilized quickly. However, the low-ability subjects had to become reacquainted with the problem before they could benefit from the hint. They better utilized the hint when it was given in the context of the problem.

Unlike Dominowski and Jenrick (1972), Murray and Denny (1969) found that high-ability subjects performed better when they were allowed continuously to work on a problem. Subjects were divided into two ability groups on the basis of their scores on the GTT. Subjects were then given Saugstad's ball problem. In this problem, subjects must stand behind a line and use a nail, pliers, string, a pulley, elastic bands, and newspapers to transfer steel balls from one container to another. Subjects worked continuously on the problem or were given an interpolated activity. Subjects with high scores on the GTT performed better on the functional fixedness problem when they were allowed to work continuously. In contrast, subjects with low-GTT scores benefited from an incubation period. Murray and Denny concluded that the incubation period disrupted the orderly search processes of the high-ability subjects and disrupted the maladaptive associations of the low-ability subjects.

Summary of Experimental Findings

Summarizing the experimental findings requires that we temporarily overlook a number of inconsistencies and even apparent contradictions in the results. Although we believe a unified theory of incubation can explain these difficulties, we would like to be clear about the empirical base upon which we intend to build.

First, incubation, defined as **any beneficial effect of an interruption upon problem solving**, appears to be a real phenomenon as the vast majority of experimental studies found incubation effects in at least one condition.

Second, incubation has been studied only in tasks that can be characterized as non-routine problem solving, although the complexity of the problems used varies greatly from solving anagrams to composing poems.

Third, subjects' knowledge of whether or not they will return to the task after a break appears not to effect incubation.

Fourth, adequate preparation time must be allowed before incubation can be expected. Longer preparation intervals appear to be required for more complex problems.

Fifth, the nature of interruption activity can be crucial. Specifically, activities that are related to the primary task are especially beneficial if they help prime the solution to the primary task. However incubation effects have been reported in experiments using both related and unrelated activities. Extremely difficult interruption tasks may cause fatigue, which can negate any benefits of any the interruption.

Sixth, the optimal length of the interruption period varies with the task, but can be expressed as a ratio of the length of preparation time allowed over the length of the interruption. When the interruption activity is unrelated to the primary task, incubation effects have been reported with this ratio typically at about 10:1. When the interruption activity is related or when other factors favoring incubation are introduced, incubation effects have been reported with ratios of 1:1 and 2:1.

Finally, individual differences can affect incubation. In some cases, high-ability subjects benefit from an interruption. In other cases, the search processes of the high-ability subjects are hurt by an interruption. Whether an interruption helps or hurts appears to depend upon an interaction between subjects' abilities and the type of problem. However this interaction, as well as other puzzling aspects of the empirical literature, are best understood within a theoretical framework.

Theories of Incubation

Most of the existing theories of incubation can be traced at least as far back as Woodworth's review of the subject at the very end of his classic text, *Experimental Psychology* (Woodworth 1938). In particular Woodworth explicitly mentions unconscious work, conscious work at periodic intervals, lack of brain fatigue, and absence of interferences (forgetting) as potential explanations of incubation. Moreover, Woodworth hints at the importance of priming from cues in the environment, although priming does not appear in his list of theories. To Woodworth's list, we would add only statistical regression and maturation (both biological and in the sense of adding knowledge and experience) as potential explanations for certain instances of incubation. Besides these two, we know of no new categorical explanations of incubation that have emerged in the 50 years since Woodworth's seminal discussion.

What is new however, is our ability to make rigorous concepts like "forgetting" and specify what they mean in terms of detailed mechanisms. We believe such mechanisms provide half of the story explaining results that seem confusing at a grosser level of description. The other half of the story can be found in the way the factors influencing incubation and these mechanisms interact.

We will begin by examining each of the major categories of explanation that have been proposed for incubation. We shall see that historically incubation has been viewed as a single process rather than as the effect of multiple processes and interactions between factors. Because we believe no single process view can account for the entire range of incubation effects that have been reported, we shall ultimately argue for a more unified theoretical framework.

Unconscious Work

Unconscious Work is perhaps the oldest theory of incubation, dating back at least to Poincare (1908 cited in Woodworth 1938). Wallas (1926), Patrick (1937), Hadamard (1945), and Eindhoven and Vinacke (1952) are also all supporters of the Unconscious Work viewpoint. In addition, the accounts of creative discovery compiled by Ghiselin (1952) and the practical advice contained in books such as Osborne's (1953) *Applied Imagination* suggest that Unconscious Work is the popular common-sense explanation for incubation. This view is intuitively appealing. Most of us have had the experience of attaining insight "out of the blue" when we were not thinking about the problem. Because we are unaware of how we arrived at the insight, we attribute our insight to the workings of the unconscious.

Poincare's essay, *Mathematical Creation* (Ghiselin, 1952), is typical of the attempts to describe the Unconscious Work hypothesis. First he notes:

Most striking at first is this appearance of sudden illumination, a manifest sign of long, unconscious prior work. The role of this unconscious work in mathematical invention appears to me incontestable... (Ghiselin 1952, p.27)

Then after remarking upon the benefits of interruption of conscious work on difficult problems, he sketches his view of the unconscious process:

It might be said that the conscious work has been more fruitful because it has been interrupted and the rest has given back to the mind its force and freshness. But it is more probable that this rest has been filled out with unconscious work and that the result of this work has afterward revealed itself to the geometer... (Ghiselin 1952, p.27)

When it comes to specifying the precise nature of the unconscious work, Poincare is quite tentative in offering hypotheses. Each hypothesis he suggests has the "subliminal self" automatically forming combinations of ideas. His preferred hypothesis seems to be that the unconscious forms only combinations of those ideas that have first been "mobilized" by previous conscious work.

Unfortunately it is precisely this vagueness which makes unconscious work an unsatisfactory explanation of incubation effects. In particular, proponents of the unconscious work hypothesis would have to explain why the unconscious is influenced by factors such as the nature of the task, the type of intervening activity, the length of the interruption period, and the timing of the interruption. Lacking such explanations, we agree with Woodworth that unconscious work "should be left as a residual hypothesis for adoption only if other, more testable hypotheses break down. (1938, p. 823)"

Conscious Work

At the other extreme from Poincaré's hypothesis of unconscious work is the view that problem solving progresses exclusively via conscious work. It may be that individuals periodically work consciously on a problem during a long incubation period. These work episodes may be brief, and, if they are not successful, they might easily be forgotten. Or, more intriguingly, perhaps they were never encoded as episodes of conscious work at all.

For example, J.E. Teeple, one of the scientists responding to Platt and Baker's (1931) questionnaire on creative thinking, proposed:

> ...In deep concentration on any subject you are not only unconscious that you are thinking, but you are unconscious of everything else around you, and I am reasonably sure that if a man is conscious that he is thinking, then at that moment he is not doing any serious thinking.
> ... If [the mind] works until the solution comes, we are liable to forget that it has worked at all. I have had such revelations come, for example, in my berth in a Pullman, reading a detective story, but on one occasion I checked this, happening to know something of the time involved and the story I was reading, and I had been looking at the same page for close to three-quarters of an hour without seeing anything at all. These are not revelations any more than any solution of a problem you are working on is a revelation. (Platt & Baker 1931, p. 1986-1987)

Although the accuracy of this report is certainly open to debate, it does suggest a potentially viable explanation for certain incubation effects. Brief periodic returns to a problem which are later forgotten would fit with the ratio data shown in Table 2. There we saw that relatively high ratios of interruption time to preparation time were needed unless a prime or other factor fostering incubation was introduced. However, four out of the five studies listed at the top of Table 2 tried to control for the possibility of conscious work by providing subjects with demanding tasks during the interruption period. Moreover periodic returns to the problem could at best be only a partial explanation of incubation, since several studies obtained incubation effects with relatively short interruption periods and one (Dreidstadt 1969) even found an interruption to be **more** helpful than the same time spent engaged in conscious work

Typically, these latter studies involved some sort of prime or hint which was given during the interruption period.

Despite these objections, the periodic conscious work hypothesis warrants further investigation, particularly since it may be relevant to many real world accounts of incubation that typically have much longer incubation periods than the experimental studies reviewed here.

Recovery From Fatigue

Like unconscious work, the recovery from fatigue explanation dates at least back to Hemholtz (1896). Unfortunately, like unconscious work, fatigue is a very ill-defined term. At the extremes, it is clear that fatigue affects problem solving. A person who cannot remain awake can scarcely be expected to make as much progress as someone who is fully alert. We would not be surprised if an interruption (for sleep) has a beneficial effect on a sleep-deprived problem solver. The difficulty comes when mental fatigue of a more vague and subtle sort is introduced as an explanation.

Even some of these subtler cases seem plausible. For example, Fulgosi & Guilford argue reasonably that working for an hour on a difficult interruption task is fatiguing whereas working on the same task for 20 minutes is not. This difference in level of fatigue, they argue, explains why a 20-minute interruption helped performance on a different primary task but a 60-minute one did not. The benefits of the interruption (perhaps due to forgetting -- see below) were outweighed by the negative effect of fatigue in the 60-minute case, but not in the 20-minute case.

Fatigue probably plays some role in accounting for incubation effects -- especially those occurring in situations where the problem solver has worked contiguously for long stretches of time on the same problem. However, for the typically short laboratory studies that we have reviewed here (excepting the case above), the role of fatigue seems minimal. At the very least, fatigue needs to be operationalized and made more precise before it can be useful in explaining incubation.

Forgetting

Woodworth suggests that "incubation consists in getting rid of false leads and hampering assumptions so as to approach the problem with an open mind" (1938, p.823). Simon (1966), elaborating substantially on this idea, writes:

What happens now, if the problem solver removes himself from the task for a

> time? Information that he has been holding in relatively short-term memory will begin to disappear, and to disappear more rapidly than information in long-term memory... Hence when the problem solver next takes up the task, many or most of the finer twigs and branches of the goal tree will have disappeared. He will begin again, with one of the higher level goals, to reconstruct that tree -- but now with the help of a very different set of information ... than he had the first time he went down the tree. In general, we would expect the problem solver, in his renewed examination of the problem, to follow a quite different path than he did originally. Since [he] ... now has better information about the problem than [he] ... did the first time, he has better cues to find the correct path. (1966, p. 33-34)

Simon's explanation highlights two important ways in which the problem solver's state of mind might change. First, like Woodworth, Simon suggests that detailed information may be forgotten during the incubation period. In addition, however, Simon points out that learning occurs during the initial failed attempts at problem solving. Forgetting clears working memory and provides the opportunity for a re-evaluation of the problem. However, it is the knowledge garnered during the initial failures that allows the re-evaluation of the problem to be a more intelligent evaluation.

Forgetting fits well with the observation that incubation effects are not observed unless there is an adequate preparation period. There must be time for entanglement in a wrong approach before forgetting can help by breaking set or fixation. If too little preparation time is allowed, subjects may not even encode the problem adequately, let alone attempt its solution. Too early of an interruption might therefore cause important elements of the problem itself to be forgotten (as opposed to details of attempted solutions) thus hindering rather than helping problem solving.

Forgetting also offers a plausible explanation for incubation in the absence of priming or other beneficial factors. Because a number of studies report incubation effects of this sort (in at least some conditions -- e.g. Mednick et al. 1964), it is likely that forgetting is at least part of the explanation for incubation effects. However, reports of incubation under circumstances where forgetting is likely to have little chance to operate (e.g Dreidstadt 1969, the *immediate* conditions of Mednick et al. 1964) suggest that forgetting cannot be the whole story.

Priming

Between the time work is stopped on a problem and when work is resumed, the problem solver may have any number of seemingly unrelated experiences that later prove to be of help in solving the problem. In anecdotal accounts of incubation, these experiences often play a critical role in hinting at, or priming the solution.

For example, Koestler (1964) tells how Benjamin Franklin originally wanted to test his theory that lightning was electricity by affixing a lightning rod to a tall spire he hoped would be erected in town. The construction of the spire was delayed, and Koestler hypothesizes that the thoughts of a frustrated Franklin may have turned toward relaxing memories of his childhood. One of these was the memory of floating on his back in the lake for hours (the young Franklin was a phenomenal swimmer) while being towed by a string attached to a kite. Here, in the memory of kites and childhood bliss, Koestler says Franklin found the germ that primed the idea of sending a kite into an electrical storm. Incubation effects occurred because Franklin took time away from the problem that allowed him to access experiences that would not have come to mind during normal work on the problem, but which nonetheless proved relevant.

Experimental studies demonstrating the effectiveness of hints (Burke, 1969; Maier, 1930) and incidental cues (Judson et. al., 1956; Mendelsohn & Griswold, 1964) support the view that apparently irrelevant events can affect problem-solving behavior -- sometimes without the solver being able later to recall the hint or cue. Some researchers have suggested spreading activation as a mechanism that might account for effects of this kind (Langley & Jones, 1988; Yaniv & Meyer, 1987). We believe that spreading activation falls under the general label of priming.

Priming has potential to explain many of the cases of incubation that forgetting could not. The complementary relationship between priming and forgetting becomes clear when viewed at the level of mechanisms. We can conceive of forgetting as the decay of activation of nodes in long-term memory while priming corresponds to an increase of activation of these same nodes (Anderson 1983). Forgetting decreases the probability that a given node will become a part of working memory, while priming increases this probability. Whereas forgetting requires a relatively long interruption period for activation to decay or for associative interference to build up, priming requires only that the interruption be long enough for the prime to be noticed.

Maturation & Statistical Regression

Maturation, in the sense of both gained experience and biological growth, is a potential explanation for incubation effects that seems to have been largely overlooked. However it seems likely that changes in perspective that accompany both aging, or biological maturation, and expertise, play some role in discoveries that Koestler (1964) tells us were "incubated" over many years. If these changes in perspective could be more clearly specified, maturation might become a predictive explanation of incubation effects. However, experiments (or detailed historical analyses) of a time scale much longer than those reviewed here would be needed to test such a theory.

Regression toward the mean is a final potential explanation of some incubation effects. If the first attempt at solving the problem is unsuccessful because the problem solver is performing below his or her normal ability level, one would expect subsequent attempts to be more successful because of regression. In this account, incubation simply reflects that people have good days and bad days. A bad day followed by a good day is likely to look like incubation. Assuming that the factors determining good and bad days could be specified, this explanation might account for many of the anecdotal accounts of incubation effects. However, since most of the experimental studies compared mean performance of groups of subjects, regression seems unlikely to be the explanation for the results that have been reviewed here.

Theoretical Implications of Individual Differences

We believe that the mixed results for incubation both as a main effect and as an individual-differences variable derive from its being studied incorrectly. *We will argue that whether incubation occurs depends not so much on the main effect of problem or subject, but on the person-problem interaction.* Consider variables that are likely to enhance the effect of incubation periods and how they would depend on the interaction between problem and person.

A first such variable is the amount of processing that occurs during the incubation period. Some people may be more prone to thinking about problems than others, but the amount of processing probably depends on how a given person responds to a given problem. Many of us find, for example, that we ponder some kinds of problems and continue to be haunted by them, whereas other kinds of problems engender little effort. In problem solving, the very same problem that excites one person can leave another person cold. Thus, the amount of processing that occurs during an incubation period is likely to depend on how a given person reacts to a particular problem. How motivated a subject is will depend, in part, on the match between the subject's abilities and the abilities required by the problem (Sternberg, 1988). For example, subjects with high spatial ability might be more motivated to solve spatial problems, such as the farm problem (Dreistadt, 1969), than non-spatial problems, such as remote associations (Gall & Mendelsohn, 1967; Mednick, Mednick, & Mednick, 1964). Similarly, subjects who are divergent thinkers might dwell more on a divergent problem, such as "What would be the results if everyone suddenly lost the ability to read and write?" (Fulgosi & Guilford, 1968), during an incubation period than they would on a convergent problem, such as the farm problem (Dreistadt, 1969).

A second such variable is whether an individual has reached a dead-end in problem solution or is on the path to a correct solution. If a person is at a dead end, an interruption seems likely to help by allowing time for useless associations to weaken and new, more useful associations to be formed (Mednick, Mednick & Mednick, 1964). If, however, a person is on a productive route to solution, the person may be better off if allowed the time to pursue this route without interruption. In this particular case, an interruption may cause the person to lose track of where he or she is in problem solving (Murray and Denny, 1969). Where the person will be in problem solution depends on an idiosyncratic interaction of the person with the problem. An interruption might help some individuals but hurt others, depending on the kind of progress each person is making.

A third interactive variable involves whether an individual has been able to use whatever clues have been provided. If a person is trying out possibilities for use of a clue, an interruption might result in the forgetting of just what possibilities have been tried. Relevant features of the problem may need to be re-encoded or certain combined features may need to be recombined after the interruption. Some routes that have been tried may no longer be stored in working memory, with the result that these routes are tried yet again. If a person has reached a dead end with a particular clue, then the incubation period may help (Dominowski and Jenrick, 1972).

A fourth interactive variable is the knowledge a given individual brings to bear on a particular problem In the hatrack problem, for example, someone with extensive experience using pole-lamps may have an advantage. The more prior information one has, the less the problem may involve insight or a change in representation and the more it may involve somewhat routine combinations and recombinations of information until a solution is reached. In other words, more prior information may allow more continuity in problem solving. The individual can simply go through a series of familiar steps to reach solution. In such cases, an incubation period may not serve its desired function, because it will disrupt this continuity. If the relevant knowledge base is meager, however, then an incubation period may be more useful because it can lead to the generation of new solution paths that depend not on prior knowledge, but on redefinitions of the problem that occur only when an inappropriate set is broken. Breaking set can be facilitated by a period away from a problem.

In sum, we are arguing that it is probably a mistake to study incubation in problem solving without considering individual differences, but it is probably also a mistake to look at individual differences without considering the particular problems being solved. The usefulness of an incubation period may be largely determined by an interaction that has not been studied -- the person-problem interaction -- and not by the main effects of either problem or persons. We thus believe that future research on incubation, like much contemporary research in the personality area, should focus on interactions rather than on main effects.

A Unified Theory of Incubation

Each of the theories of incubation discussed so far seems capable of explaining at least some incubation effects. But none seems capable of explaining the entire experimental literature, including the apparent contradictions. If progress is to be made we believe researchers must begin thinking in terms of unified theories of incubation that are capable of accounting for all of the results in the literature. We propose the following framework, not as a complete and comprehensive theory of incubation, but rather as an illustration of the direction we hope future research on incubation will take.

Our unified theory begins with the key issue of problem difficulty and adopts the widely known conception of problem solving as search through problem spaces (Newell, 1980; Newell & Simon 1972). Within this search framework, there are at least three ways that a problem might be hard:

1. The problem solver may have **too many paths** and no good way of deciding which path to choose.

2. The problem solver may be completely **unable to generate any new paths**, and can only stare blankly at the problem.

3. The problem solver may be capable of generating a number of different paths, but suffers from **stereotypy**. That is, the problem solver persists in generating paths only from a narrow set.

We suggest that the same variables that we have discussed as influencing incubation might have their effect primarily by determining which of these three types of difficulties a problem solver is likely to encounter. For example, a relevant dimension of the *primary-task* variable is the amount of branching of a task's search space. A task with a large, well-defined search space, like chess, often is difficult because there are **too many paths**. Anyone who knows the rules can always generate moves exhaustively. The difficulty lies in choosing which paths to explore.

In contrast, many insight problems typically have points at which the subject cannot think of anything to do next. In these cases, the obstacle is of the type **unable to generate any paths**. Some insight problems (e.g. The Mutilated Checkerboard Problem, Kaplan & Simon, 1988) are difficult because they trick subjects into trying the wrong approach at first. Subjects typically suffer from stereotypy as they repeatedly try slight variations of this seductive, but incorrect, approach. Eventually the subjects become frustrated but are unable to think of anything new. Hence, it is quite possible for both stereotypy and inability to generate new paths to occur in the same problem at different times.

Such timing considerations provide a clue as to why the length of the preparation interval may be an important variable in incubation experiments. If a subject is interrupted quite late, he or she may have already passed through a period of stereotypy and now may be unable to generate new paths. Given the hypothesis that the helpfulness of an interruption depends critically upon the type of difficulty a subject is experiencing, it follows that, for some problems, incubation effects should depend upon the timing of the interruption.

Individual differences are also likely to affect the type of obstacles subjects encounter during problem solving. Differences in knowledge allow one subject to suffer from stereotypy (repeated application of inappropriate knowledge) while another subject, perhaps lacking this inappropriate knowledge, may suffer from an inability to generate any options at all. Such differential effects of knowledge have been documented in the case of at least one insight problem (Kaplan & Simon, 1988). It is easy to imagine how other individual differences -- for example, differences in the ability to generate new paths -- might result in some subjects having too many paths to choose from, whereas others are unable to generate any new paths at all.

Mechanisms X Problem Difficulty

To account for the range of incubation effects reported in the literature, we need to consider the interaction between a given mechanism for incubation and the specific type of difficulty that a subject experiences. In particular, we will focus on the mechanisms of priming and forgetting (decay of activation) because they can account for most, if not all, of the empirical results, once their interaction with problem difficulty is understood. For the sake of simplicity, we will also consider only the two types of difficulty that are most characteristic of insight problems: the inability to generate any paths, and stereotypy. Table 4 shows the critical predicted interactions.

<INSERT TABLE 4 ABOUT HERE>

We envision both priming and forgetting as occurring within a spreading- activation model of human memory (Anderson, 1983). When a prime is presented, the activation levels of associated information in long-term memory increase. If the prime is strong enough, the activation levels may cross a threshold and enter working memory. Otherwise, the ease with which the information can enter working memory, or equivalently the probability of retrieving that information, increases in proportion to the strength of the prime.

Forgetting can occur in two ways, both explainable in terms of a spreading- activation model. First, the activation level of information in long-term memory is always decaying toward some baseline rate. So, the passage of time alone is sufficient to cause forgetting. In addition, because of the fan effect, the activation of new (previously inactive) information can make it harder to recall other information that is quite similar (Anderson 1981).

A prime should help most when a subject is unable to generate any new paths, because attention is more likely to be focused on the prime and there is little activation of competing information. A prime should be of no help, however, if the subject is strongly focused on another path, as in the case of stereotypy.

In contrast, forgetting should help subjects suffering from stereotypy because it provides an opportunity for the activation of these misleading paths to decay. Conversely, forgetting should be of little help if the subject is simply unable to generate any new paths. Assuming that the subject has simply run out of things to try, there is nothing to forget.[7]

Accounting for the Data

One problem that any unified theory of incubation must face is dealing with the relatively sparse data about the *process* of problem solving. Perhaps the best way to determine the type of difficulty a subject is experiencing during problem solving is to obtain concurrent verbal reports by asking subjects to think aloud as they work (Ericsson & Simon, 1984). But protocol data have not been reported in 13 of the 17

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[7] If it turns out that the subject cannot generate new options because some information is blocking this generation process, then we would expect forgetting to help. However, whether inability to generate new paths is a function of such blocking or simply exhaustion of ideas will probably depend upon the problem and the subject's current state in problem solving.

studies. We must therefore do the best we can with the data at hand, recognizing that many "ifs" will exist that will have to be verified by the results of future experiments. Because our aim is to illustrate the direction in which further research should move (namely, toward unification in general), we will not be overly concerned at this stage about the gaps that currently exist.

We will argue that the mechanisms of priming and forgetting are sufficient to account for the reliable results of studies using the standard experimental paradigm for incubation (i.e. comparison of performance during continuous and interrupted work periods of the same total length -- excluding the length of the interruption period). However, for the sake of completeness, we begin by discussing briefly those studies which fall outside of this scope. Such studies include those of Catherine Patrick (1935, 1937, & 1938), Eindhoven and Vinacke (1952), Gall and Mendelsohn (1967), Olton and Johnson (1976), and Kirkwood (1984).

In the case of the studies by Patrick (1935, 1937, 1938) and Eindhoven and Vinacke (1952), incubation was defined differently from the way it has been used in this paper. Patrick considered incubation to be simply "the recurrence of ideas" during problem solving. Because the problem-solving strategy of **best first search** leads to recurrence of ideas, this definition of incubation can be accounted for in terms of conscious problem solving. Eindhoven and Vinacke define incubation as "thought about the problem conscious or not" and present no evidence that anything other than normal problem solving is occurring

The major finding of Gall and Mendelsohn (1967) regarding incubation was that continuous work on the primary task was more beneficial than time spent on an unrelated psychophysical judgment task. Note that this comparison is different than the typical comparison of total time spent in continuous work versus the same time divided into two work periods which are separated by an interruption period. The mechanisms of forgetting and priming would need an exceptional opportunity to have an effect if the time spent during an interruption period is to be more useful than the same time spent in conscious work (see the discussion of Dreistadt's experiment below). Gall and Mendelsohn provided no such opportunities in their design. The interpolated judgment task was specifically chosen so as to minimize interference with the primary task. However, such a choice also tends to minimize the likelihood of forgetting. Moreover because the interpolated judgment task was completely unrelated to the primary task, the opportunity for priming was negligible. Considering these conditions, the experimental finding that more conscious work is better seems to be just what one would expect.

Their other interesting finding, that free association for females interacting with female experimenters was approximately equal in benefit to conscious work, also seems reasonable. To begin with, the difference between free associating to RAT items and actually working on RAT items is potentially quite small. Once social psychological factors concerning inhibitions about free associating in the presence of an experimenter of the opposite sex are taken into account, that slight difference might reasonably disappear altogether, as Gall and Mendelsohn report. Again the results seem entirely consistent with psychological principles, independent of any incubation mechanisms.

We have already discussed at length how the high performance of the control group in Olton and Johnson's study makes their results difficult to interpret. Because most of their interrupted groups performed as well as the controls and because the reason for the good performance of the controls awaits further replication attempts, we are left with the task of explaining the exceptionally poor performance of two incubation groups: the stress reduction group, and the set-breaking lecture plus unobtrusive visual analogies group. Subjects in the former group listened to classical music and were encouraged to relax. We conjecture that some of them may have relaxed too much and lost motivation by the time they returned to the primary task. The group that received a lecture on set breaking was presumably motivated to search for new approaches to the problem. This attitude would have been helpful except that they were provided with an array of "unobtrusive pictures," most of which were completely irrelevant to the problem. It is quite possible that subjects did look for new approaches but had a high probability of finding misleading ones in the irrelevant pictures.

With a final exclusion of Kirkwood's study due to the major flaws that were discussed earlier, we can begin an account of the results of the remaining studies (including some results which were previously unexplained) in terms of our unified approach.

Fulgosi and Guilford (1968, 1972), Silveira (1971), Peterson (1974), and Beck (1979) report incubation results that can be interpreted fairly simply as forgetting interacting with stereotypy. Table 2 shows that these five studies all had relatively high ratios of incubation time to preparation time. A high ratio is just what we would expect if time were needed for the activation of inappropriate information (i.e., information leading to stereotypy) to die down. Thus, a simple forgetting, or decay-of-activation, mechanism may be able to account for the positive reports. In certain conditions of the experiments where incubation effects failed to occur, the reason can be traced to an interruption that was too short (relative to the needed preparation time) for much decay to occur (Beck, 1979; Fulgosi & Guilford, 1968; Silveira, 1971), to a lack of adequate preparation period (Silveira, 1971), or to the negative effects of fatigue resulting from long work at a very difficult interruption task (Fulgosi & Guilford, 1972).

Dreistadt (1969) reports results that can be interpreted most simply as priming. Interrupting work on the farm problem for eight minutes of card guessing did not lead to any incubation effects because (a) the interruption was short relative to the required preparation time, (b) the continuous-work subjects got an extra eight minutes of conscious work on the problem, which ought to more than offset the minimal benefits of forgetting over such a short interruption interval. On the other hand, presenting a subtle relevant prime (in the form of pictures) to the subjects while they worked on the problem did lead to better performance as we might expect. The fact that the pictures were present throughout the problem-solving episode increased the probability that subjects would notice the prime when they reached a point of inability to generate new options -- the point at which we hypothesize subjects ought to be most receptive to such a prime. Finally, Dreistadt reports an interaction between an interruption period and priming such that the highest number of subjects solved the problem when they received both a break and were exposed to the pictures. This interaction can be understood when we consider that the interruption period is likely to have increased the probability of noticing the pictures. Thus, priming remains the mechanism that explains incubation, but an interruption can increase the probability of noticing a subtle prime.

The results of Murray and Denny (1969) and Dominowski and Jenrick (1972) appear at first to be in direct contradiction. Murray and Denny report that low-ability subjects benefit from an interruption, whereas high-ability subjects perform best if allowed to work continuously. In contrast, Dominowski and Jenrick report that "For Ss of high ability, the hint produced slightly faster solutions when given after a period of interpolated activity while low ability Ss made better use of the hint when it was given during continuous work." We believe the words "ability" and "hint" are the keys to resolving the apparent conflict in results.

We would essentially agree with Murray and Denny's analysis of their results. They attribute the beneficial effect of an interruption for low ability subjects to forgetting, arguing that "their problem solving processes may have been characterized by initial blocking or fixation on stereotyped responses to the available objects." Because Murray and Denny collected verbal protocols, presumably they are better equipped to make such a judgment than other experimenters without such data. They further argue that high-ability subjects were disrupted by the interruption. Since subjects had no fixations to forget, and because the preparation was relatively short (5 minutes), this interpretation also seems reasonable to us

In short, forgetting should help only if stereotypy is the source of difficulty. In Murray and Denny's experiment, it seems likely that only the low-ability subjects suffered from stereotypy.

Turning to the results of Dominowski and Jenrick (1972), we note first that low-ability (again measured by the GTT) subjects benefited from a hint only after an interpolated activity. This is not surprising because low GTT Ss are those most prone to stereotypy. Our theory predicts that such subjects will be unable to benefit from a hint (because of their fixation on incorrect approaches). However, if time is allowed for the fixation to decay, then the subjects should no longer suffer from stereotypy and the hint should lead to beneficial effects. On the other hand, subjects **not** suffering from stereotypy (i.e., the high GTT subjects) should be able to use the hint effectively without any need for an interruption period. If anything, the interruption might be slightly detrimental as it would force them to do some recoding of the problem when they return from the break. This explanation fits precisely the results reported by Dominowski and Jenrick. In short, the same general theory of priming and forgetting interacting with types of problem difficulty has potential for explaining what up until now were seen as contradictory findings.

Our final concern will be to suggest how a unified theory might be able to explain findings which have been previously unexplainable. Both Mednick et al. (1964) and Andrew Patrick (1986) conducted incubation studies using the Remote Associates Test (RAT) as the primary task. Both found results which were somewhat puzzling, but which we feel might be understandable using a more unified approach.

Table 5 shows the results Mednick et. al. reported, adapted from their Table 1 (Mednick et al. 1964 p 87).

<INSERT TABLE 5 ABOUT HERE>

Earlier we noted that these results confirmed the efficacy of priming and raised some unanswered questions with regard to individual differences in ability. Specifically, Mednick et. al. concluded:

> **The small amount of incubation that did occur in the absence of specific [relevant] priming has not been explained and needs further study, as does the fact that the high RAT scorers seem to incubate more readily than do the low scorers.**

That is, why should high ability subjects benefit from an interruption without a relevant prime (column 2) whereas low-ability subjects show no such benefit (column 4)?

Because the RAT measures ability to generate remote associations to a stimulus, it seems reasonable that high-ability subjects would generate more potential candidates and, thus, experience more associative interference than low-ability subjects. The mechanism of forgetting, or decay of activation, would therefore help the high-RAT subjects more than the low-RAT subjects, explaining the observed difference.

A more complex puzzle is why priming appears to help high ability subjects (column 1) more than low-ability subjects (column 3). Our theory suggests that we turn to an interaction between priming and forgetting for an explanation. First, an immediate (relevant) prime is better than no (relevant) prime (row 1). We would view this result as the straightforward beneficial effect of priming with high ability Ss possibly being more sensitive to primes as Mednick et al. (citing Mendelsohn & Griswold, 1964) suggest.

Now, when the prime is followed by a 24-hour break, its activation should decay, and its benefit should decrease correspondingly. The performance of both subjects should be hurt, and indeed the low-ability subjects seem to suffer (column 3, rows 1 & 2). However, the high-ability subjects receive a benefit due to forgetting that we have argued the low ability Ss should not enjoy. If the benefit due to decay of associative interference offsets the detriment due to decay of the prime, then the high ability subjects will perform as well after a 24-hour break as they did when they got an immediate prime (column 1, rows 1 & 2).

Consistent with this account is the prediction that high-ability subjects should do best when the prime *follows* a 24-hour break, because they would reap the benefits of **both** forgetting and priming. Table 5 (column 1, row 3) verifies this prediction. The low-ability subjects appear to reap some of these same benefits (column 3, row 3). However, presumably the benefit is due mainly to priming as argued above.

The point of performing this rather detailed analysis is to demonstrate how a unified theory involving both forgetting and priming can account for results that seem puzzling when either mechanism is considered in isolation. The power comes from considering interaction of factors that sometimes act in opposite ways simultaneously. Without going into too much detail, we suggest that an account similar to the one given above might explain the somewhat puzzling results of Patrick (1986).

Briefly, Patrick's results suggest that subjects of high-RAT ability perform better on RAT items when they have longer breaks, and when these breaks are of an increasingly non-verbal nature. We suggest these conditions maximize potential for decay of associative interference. On the other hand, subjects of low RAT ability, who presumably suffer less from associative interference, do not benefit much from forgetting. However, they could benefit from priming. We suggest that circulating through the RAT problems continuously serves to prime new possibilities for low-ability subjects, whereas such circulation (without an additional break) acts primarily to prevent the decay of interference for the high-ability subjects. Once one assumes that the mechanisms of priming and forgetting may be differentially affecting low and high ability subjects in different conditions, the results reported by Patrick appear much more understandable.

Conclusions

Our conclusions about the existence of incubation effects under certain circumstances have practical implications for lay people as well as for researchers. Folk wisdom tells us to "walk away from a problem when you get stuck." Our analysis suggests this advice may be more useful than it first appears. Besides any benefits due to recovery from fatigue, interrupting work on a problem provides an opportunity for the mechanisms of forgetting and priming to do their work. The details of particular solution attempts may be forgotten, forcing a re-evaluation of a wider range of solution approaches upon return to the problem. Not only will this re-evaluation be made in light of the knowledge gleaned from previous failures, but it will also be made in light of new experiences occurring during the interruption interval.

Sales people seem to have an intuitive grasp of these principles, when they pressure for on-the-spot decisions. The sales pitch primes a certain way of thinking about the decision to buy, and the salesperson does everything possible to ensure that the customer remains fixated on this way of thinking. Time away from the salesperson allows forgetting and priming to work. The customer may see new holes in the sales pitch, or may be exposed to new input (a neighbor's comments, or a newspaper article) that primes a different way of thinking.

For researchers, our analysis implies that in experiments investigating insight and transfer in problem solving, failure of subjects to perform at a high level may be due to lack of incubation time. Studies as old as Maier (1931) and as recent as Davidson (1986) link insight to subtle primes or hints. Inasmuch as an interruption provides opportunities for such external primes to arise naturally, incubation periods should facilitate solution of tough insight problems. In addition, forgetting may help alleviate stereotypy which constitutes one source of difficulty in some insight problems (Kaplan & Simon 1988).

Similarly, if the essence of transfer involves considering an old piece of information in a new context, then both forgetting the old context and priming the new context ought to help. Again an incubation period provides an opportunity for these processes to play a larger role.

In order to test these implications however, researchers may have to expand the scope of their experiments. The typical 50-minute problem solving experiment leaves little time for forgetting to act if the problem is at all complex. Similarly, spontaneous priming from the environment is not likely to occur, although experimenters still have the option of introducing primes as a manipulation as Gick and Holyoak (1980, 1983) often did in their transfer experiments. It would be interesting to see if an interruption period of the appropriate length might provide facilitation similar to that produced by these explicit hints.

On a less speculative note, our analysis has several implications for the further study of incubation. Incubation effects (defined as any positive effects of interruptions on problem solving) are real, but complex. An incubation period can serve several functions; how well it serves them will depend upon a number of interacting variables. These include the nature of the primary task, the timing and length of the interruption, the nature of the activity performed during the interruption, and individual differences in the knowledge and abilities of subjects.

Because these variables can interact in complex ways, some experiments done to date appear contradictory. It would take much more knowledge than we now have to disentangle unambiguously the effects of time, problem difficulty, individual differences, and interpolated tasks upon incubation. But we believe that further work on solving the problem of incubation requires as a prerequisite a recognition of just what the problems are that are associated with the phenomenon and its study. Without such problem recognition, researchers will go on indefinitely obtaining inconclusive and seemingly contradictory results.

We have argued that a good way to address the complexities of incubation research is to strive for a unified theory of incubation phenomena. We proposed one such theory to illustrate the potential power of a unified approach. While strong claims for the accuracy of this particular theory would be premature, the attention paid to mechanisms and interactions between factors seems to be a step in the right direction. Much research needs to be done on the way towards an empirically tested unified theory of incubation.

However, we believe the goal is attainable.

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Table 1

Tasks used in Incubation Experiments

Study	Task Description	Experiment Length*	Interpolated Activity
Patrick (1935)	Poem Composition	30 min.	N.P.
Patrick (1937)	Draw Picture	30 min.	N.P.
Patrick (1938)	Design Experiment	13 min.-3 weeks	unrelated
Eindhoven & Vinacke(1952)	Draw/Paint Picture	1 hr.- months	N.P.
Mednick et. al. (1964)	Remote Associates Test	40 min.-24 hr.	related
Gall & Mendelsohn (1967)	Remote Associates Test	2 hours	related
Fulgosi & Guilford (1968)	Generate consequences in "what if" scenarios	8 - 28 min.	unrelated
Dreistadt (1969)	Farm & Tree Problems (insight problems)	20 min.	related
Murray & Denny (1969)	Saugstad's Ball Problem (an insight problem)	20 min.	unrelated
Silveira (1971)	Solve Cheap Necklace problem (an insight problem)	35 - 245 min.	unrelated
Fulgosi & Guilford (1972)	Generate consequences in "what if" scenarios	8 - 68 min.	unrelated
Dominowski&Jenrick (1972)	Maier's Hatrack Problem (an insight problem)	20 min.	related
Peterson (1974)	anagrams	24 min.	related
Olton & Johnson (1976)	Dreistadt's Farm Problem (an insight problem)	30 - 45 min.	related
Beck (1979)	Brainstorm for uses of "Luminium"	24 - 54 min.	unrelated
Kirkwood (1984)	Group brainstorming on campus life issues	30 min.	related
A. Patrick (1986)	Remote Associates Test	1.75 - 2 hrs.	related

* Length of the experiment can vary depending upon which condition subjects were in.

Table 2

Ratios of Interruption Length to Preparation Time

Study & Result	Most Beneficial Interruption Length	Preparation Time	Ratio I:P
Studies Reporting Benefit of Interruption Alone			
Fulgosi & Guilford (1968)	20 min.	2 min.	10:1
Fulgosi & Guilford (1972)	30 min.	2 min.	15:1
Silveira (1971)	210 min.	13 min.	16:1
Peterson (1974)	120 sec.	20 sec.	6:1
Beck (1979)	30 min.	12 min.	3:1
Studies Reporting Benefit of Interruption + Another Factor			
Mednick et. al. (1964)	24 hr.	2 min.	1440:1
Dreistadt (1969)*	8 min.	5 min.	2:1
A. Patrick (1986)	4 min.	2 min.	2:1
Kirkwood (1984)	10 min.	10 min.	1:1
Dominowski&Jenrick (1972)	5 min.	5 min.	1:1
Murray & Denny (1969)	5 min.	5 min.	1:1
Studies Reporting Null or Negative Effects in All Conditions			
Gall & Mendelsohn (1967)*	25 min.	10 min.	3:1
Olton & Johnson (1976)	15 min.	10 min.	2:1
Studies Whose Design Prohibits Ratio Analysis			
Patrick (1935)			
Patrick (1937)			
Patrick (1938)			
Eindhoven & Vinacke (1952)			

* Subjects in the continuous work condition were allowed extra work time equal to the length of the interruption enjoyed by interrupted subjects.

Table 3

Primary Tasks and Interruption Activities for 13 Studies

Study	Task Description	Interpolated Activity	Incubation?
Mednick et. al. (1964)	Remote Associates Test (RAT)	Analogy problems (relevant & irrelevant) & Free time	YES
Gall & Mendelsohn (1967)	Remote Associates Test (RAT)	Association training, or Psychophysical judgments	YES
Fulgosi & Guilford (1968)	Generate consequences in "what if" scenarios	Number series task	YES
Dreistadt (1969)	Farm & Tree Problems (insight problems)	Card guessing: W/ & w/o visual primes	YES
Murray & Denny (1969)	Saugstad's Ball Problem	Logical syllogisms, or Complex tracing task	YES
Silveira (1971)	Solve Cheap Necklace Problem	Read book, or Free time	YES
Fulgosi & Guilford (1972)	Generate consequences ("what if" scenarios)	Number series task	YES
Dominowski&Jenrick (1972)	Maier's Hatrack Problem	Free association, or Anagrams (w/ & w/o hints)	YES
Peterson (1974)	anagrams	Other anagrams that were also part of task	YES
Olton & Johnson (1976)	Dreistadt's Farm Problem	Various Combinations Of: Relaxation, Free time, Active review, Stroop task, Card guessing, Set breaking lecture, Visual primes, Counting backwards by threes	NO
Beck (1979)	Brainstorm for uses of "Luminium"	Relaxation, or Essay writing	YES
Kirkwood (1984)	Group brainstorming on campus life issues	Brainstorm: on related, or unrelated topic	YES
A. Patrick (1986)	Remote Associates Test (RAT)	Other RAT items: Alone, w/ conversation, or w/ mental rotation	YES

Table 4

Predicted Interactions Between Problem Difficulty Type & Mechanisms

	INABILITY TO GENERATE NEW PATHS	STEREOTYPY
Priming	Best chance of helping. Subjects are in a receptive state.	No help at all. Subjects are preoccupied and not receptive to a subtle prime
Forgetting	Will not help at all. There is nothing to forget (assuming past responses are not creating "blocking" to associative interference).	Should help a lot. Activation of most dominant response will decay, allowing consideration of other responses.

Table 5

Results adapted from Mednick et. al., 1964

Mean Number of Remote-Associates Items

Correct Following Incubation

Incubation	High RAT ability		Low RAT ability	
	Relevant Prime	Irrelevant	Relevant Prime	Irrelevant
Immediate prime	1.50	0.50	0.50	.25
Prime followed by 24 hr. break	1.50	1.00	0.25	.50
24 hr. break 1st then prime	1.75	1.00	0.75	.25